Biodiesel Production from Palm Oil, Its By-Products, and Mill Effluent: A Review

Zahan, Khairul; Kano, Manabu

energies

MDPI

Review

Biodiesel Production from Palm Oil, Its By-Products, and Mill Effluent: A Review

Khairul Azly Zahan [1,2] and Manabu Kano [1,*]

[1] Department of Systems Science, Graduate School of Informatics, Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan; zahan.azly.47m@st.kyoto-u.ac.jp

[2] Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Parit Raja 86400, Batu Pahat, Johor, Malaysia

* Correspondence: manabu@human.sys.i.kyoto-u.ac.jp; Tel.: +81-75-753-3369

Received: 18 July 2018; Accepted: 9 August 2018; Published: 16 August 2018

check for updates

Abstract: The sustainability of petroleum-based fuel supply has gained broad attention from the global community due to the increase of usage in various sectors, depletion of petroleum resources, and uncertain around crude oil market prices. Additionally, environmental problems have also arisen from the increasing emissions of harmful pollutants and greenhouse gases. Therefore, the use of clean energy sources including biodiesel is crucial. Biodiesel is mainly produced from unlimited natural resources through a transesterification process. It presents various advantages over petro-diesel; for instance, it is non-toxic, biodegradable, and contains less air pollutant per net energy produced with low sulphur and aromatic content, apart from being safe. Considering the importance of this topic, this paper focuses on the use of palm oil, its by-products, and mill effluent for biodiesel production. Palm oil is known as an excellent raw material because biodiesel has similar properties to the regular petro-diesel. Due to the debate on the usage of palm oil as food versus fuel, extensive studies have been conducted to utilise its by-products and mill effluent as raw materials. This paper also discusses the properties of biodiesel, the difference between palm-biodiesel and other biodiesel sources, and the feasibility of using palm oil as a primary source for future alternative and sustainable energy sources.

Keywords: biodiesel; palm oil; by-products; mill effluent; properties; sustainability

1. Introduction

Biodiesel produced from different triglyceride sources is an alternative fuel to petro-diesel. The American Society for Testing and Materials (ASTM) defines biodiesel as mono-alkyl esters produced from various lipid feedstocks including vegetable oils, animal fats, etc. Furthermore, it has been accepted as a fuel and fuel additive worldwide and registered with the U.S. Environmental Protection Agency (EPA). Owing to the worries about petroleum availability and the current increase in petroleum price, the usage of biodiesel in conventional diesel engines has attracted much attention. The history began in the 1900s when Sir Rudolf Diesel successfully run conventional diesel engines using vegetable oil without any modification. In the 1930s and 1940s, vegetable oil was utilised as diesel fuel, particularly in the emergencies [1]. However, further investigation has verified that the direct usage of vegetable and animal oils as diesel fuel is impractical due to their large molecular mass, low volatility, and high kinematic viscosity, which reduce the performance of the engine and raise other problems including thickening, gelling, and sticking of the oil [2]. To overcome these problems and allow its application as a fuel, several methods have been implemented such as blending with petro-diesel, microemulsification, pyrolysis, and transesterification, as summarised in Table 1 [3–8].

Table 1. Preparation and production of biodiesel using different methods [3–8].

Methods	Main Process	Advantages	Disadvantages
Blending (dilution)	Preheated vegetable/animal oils were blended with petro-diesel within 10–40% (*w*/*w*) ratio. Then the resulted oil-diesel mixture was applied into the diesel engine.	Does not required any chemical process (non-polluting), absence of technical modifications, and easy implementation.	High viscosity, unstable, low volatility, and increase in vegetable/animal oil portion resulted in improper spraying pattern, poor atomization, incomplete fuel combustion, and difficulty in handling by conventional engines.
Microemulsification	The vegetable/animal oils were solubilized in a solvent (alcohol) and surfactant until the required viscosity was obtained.	Simple process and pollution free.	High viscosity, low stability (the addition of ethanol can enhance the quantity of surfactant required to maintain the state of microemulsion), and could lead to sticking, incomplete combustion, and carbon deposition.
Pyrolysis (thermal cracking)	The vegetable/animal oils were preheated and decomposed at elevated temperature (more than 350 °C) whether or not the catalyst is present. Different products (gas and liquid) were analysed based on their boiling temperature range to determine the exact product.	The process is effective, simple (not required washing, drying or filtering), wasteless, and pollution free.	Required high temperature and expensive equipment and produce low purity of biodiesel (contain heterogeneous molecules including ash and carbon residues).
Transesterification	The vegetable/animal oils and fats were reacted with alcohol (ethanol or methanol) and catalyst (alkali or acid). Then the mixture of methyl/ethyl esters (biodiesel) and glycerol (byproduct) will undergo separation and purification steps before further usage.	High conversion with relatively low cost, mild reaction conditions, product properties are closer to the petro-diesel, and applicable for industrial-scale production.	Required low free fatty acids (FFAs) and water content in the raw material, extensive separation and purification steps, possibilities of side reaction to occur, and generation of a large amount of wastewater.

1.1. Biodiesel Production Routes

Among the various methods, the most common method used in producing biodiesel is a transesterification process. In this process, lipid feedstocks are converted into biodiesel. One mole of triglyceride reacts with three moles of alcohol to produce three moles of mono-alkyl ester and one mole of glycerol. To improve the rate of reaction and biodiesel yield, a catalyst is usually added with excess alcohol, which shifts the equilibrium to the product side since the reaction is reversible [1,9,10]. Traditionally, the transesterification process utilises solvents including ethanol or methanol and homogeneous catalysts such as KOH, NaOH, and H_2SO_4 [11–13]. However, this method has several shortcomings such as extensive separation process, wastewater generation, and equipment corrosion [13–16]. To overcome these problems, various studies have been conducted such as the implementation of heterogeneous catalysts. To date, many types of heterogeneous catalysts such as solid acid and base, zeolite, and polymer have been widely utilised so that the recovery process becomes straightforward and the purification steps are minimised [17–20]. Nonetheless, as compared to homogeneous catalysts, heterogeneous catalysts are less effective due to long reaction time (up to 24 h), low reaction and conversion rate, easy deactivation, and high viscosity that increases the mass transfer resistance. In addition, heterogeneous catalysts also require high reaction temperature, pressure, catalyst concentration, and alcohol-to-oil molar ratio, which basically lead to the increment in the overall production cost [13,14,16,21,22].

The use of biocatalysts, i.e., enzymes and microbial cells, in the transesterification reaction is also possible [23,24]. For instance, the use of *Pichia pastoris* yeast whole cell catalyst was implemented for biodiesel production from waste cooking oils [23]. The study found that up to 82% biodiesel production could be obtained within 84 h. Alternatively, lipase can also be used as a biocatalyst for production of biodiesel [24]. This process takes place in two steps involving the hydrolysis of an ester bond and esterification with the second substrate. The implementation of the biocatalyst for biodiesel productions remains challenging since it has several issues such as high preparation cost, reusability issues, low stability, and durability of the native enzymes [25–27].

Recently, a new type of chemical, the so-called ionic liquids (ILs), and non-catalysed routes under supercritical conditions have gained attraction among researchers [28–31]. Even though both strategies have been successfully performed on a laboratory scale, their industrial acceptance and application are still limited due to their high capital and operational cost, non-conformity of the recovery methods, low reusability of ILs, and several technical and operational challenges, including the requirement of heating instrument and high-pressure vessels resulting in high energy demand [32–36]. Thus, the transesterification using homogeneous catalyst is still the most favourable and applicable process for producing biodiesel on an industrial scale.

1.2. Properties of Biodiesel

In recent years, the research, development, and commercialisation of biodiesel have been boosted due to the urgency of finding the best solution to the world energy crisis. We cannot continue to rely heavily on crude petroleum as the primary source of transportation fuels and electricity. Although many alternative energies such as solar, wind, biomass, and geothermal, only biofuel or biodiesel can be used on a large scale, especially for transportation, due to its reliability and economic feasibility [37]. Moreover, biodiesel presents several advantages such as non-toxicity and eco-friendly properties, compatibility with existing diesel engines without extensive engine modifications, and the huge amount of renewable sources currently available worldwide [38,39]. The quality of biodiesel can be evaluated on the basis of two major guidelines, i.e., the U.S. Specification (ASTM Standard) and the European Specification (EN Standard). Table 2 summarises the major properties of biodiesel based on both standards.

The use of biodiesel significantly diminishes the emissions of harmful GHG, particulate matter, and hydrocarbons but slightly rises fuel consumption and reduces the engine power. Although NOx emissions are increased in some cases, this can be minimised using exhaust gas recirculation (EGR) or other additives [40]. A comparison of biodiesel properties is tabulated in Tables 3 and 4. It was confirmed that biodiesel produced from natural and renewable resources is an excellent alternative for existing petro-diesel, especially for transportation. As shown in Table 3, biodiesel has superior properties to petro-diesel in many areas: for example, higher cetane number (a significant advantage regarding engine performance and emissions), low ash content, and low carbon residue, whereas the other properties can be improved by using blending processes [41]. Moreover, Table 4 shows an interesting feature of biodiesel (rapeseed methyl ester) due to low exhaust emissions of CO and NOx, which is one of the major concerns for any engine or fuel [42]. Datta and Mandal [43] reviewed the effects of various types of biodiesel on major performance parameters of compression ignition engine. When biodiesels were used instead of petro-diesel, they discovered that brake fuel consumption and thermal efficiency were generally decreased. On the other hand, exhaust gas temperature and emissions of CO, hydrocarbon, and smoke reduced with the use of biodiesel.

Table 2. Properties of biodiesel [4,9,15,17,32,38,40,41].

Properties	ASTM D6751	EN 14214
Flash point, min (°C)	100–170	≥120
Cloud point (°C)	−3–−12	- *
Pour point (°C)	−15–−16	- *
Kinematic viscosity at 40 °C (mm^2/s)	1.9–6.0	3.5–5.0
Specific gravity at 15 °C (kg/L)	0.88	0.86–0.90
Density at 15 °C (kg/m^3)	820–900	860–900
Cetane number, min	47	51
Iodine number, max	- *	120
Acid number, max (mg KOH/g)	0.50	0.50
Ash (wt %)	0.02	- *
Sulphated ash, max % (m/m)	0.02	0.02
Oxidation stability, min (h, 110 °C)	3	6
Water and sediment, max (v/v %)	0.05	0.03
Water content, max	0.03 (v/v)	500 (mg/kg)
Free glycerol, max (mass %)	0.02	0.02
Total glycerol, max (mass %)	0.24	0.25
Sulphur content, max	0.05% (m/m)	10 mg/kg
Phosphorus content, max	0.001% (m/m)	10 mg/kg

* Not specified.

Table 3. Comparison between biodiesel and petro-diesel [41]. Reprint with permission [41]; 2009, Elsevier.

Properties	Petro-Diesel	Biodiesel from Waste Cooking Oil
Flash point, min (°C)	67–85	196
Pour point (°C)	−19–−13	−11
Kinematic viscosity at 40 °C (mm^2/s)	1.9–4.1	5.3
Density at 15 °C (kg/m^3)	75–840	897
Cetane number, min	40–46	54
Ash content (%)	0.008–0.010	0.004
Carbon residue (%)	0.35–0.40	0.33
Sulphur content (%)	0.35–0.55	0.06
Water content (%)	0.02–0.05	0.04
Higher heating value (MJ/kg)	45.62–46.48	42.65

Table 4. The exhaust gases emissions recorded in a modified 1D80 Hatz direct-injection engine with full load and torque of 36 Nm at 1800 rpm [42].

Properties	CO (ppm)	NOx (ppm)
Diesel fuel	655	1270
Jatropha curcas (vegetable oil)	601	1280
Rapeseed (vegetable oil)	910	1235
Rapeseed methyl ester (biodiesel)	555	1180

In short, biodiesel has attracted much attention due to its various environmental benefits. However, the main challenges include its production cost and availability of suitable raw materials. Although biodiesel can be synthesised from different types of raw materials, their price and availability are among the most significant factors that must be considered. Aarthy et al. [44] mentioned that the raw materials account for 60–80% of the total production cost of biodiesel. High production cost affects the processing economic feasibility and selling price of biodiesel. For instance, the current selling price of biodiesel (B99–B100) in the USA is around 15–30% higher than that of diesel, as shown in Table 5. Despite the ongoing progress of the biodiesel industries, their sustainability may be restrained by the difficulty in securing cheap raw materials. Minimising the production cost is crucial so that the biodiesel selling price can be more competitive. Thus, this paper focused on the utilisation of palm oil, its by-products, and mill effluent as raw materials for producing biodiesel. It is believed that the biodiesel production cost can be reduced by using wastes apart from improving the quality of the environment.

Table 5. The USA average fuel price.

Properties	Price ($/gallon) [45]		
	1–31 July 2017	1–31 October 2017	1–30 April 2018
Biodiesel (B20)	2.49	2.68	2.87
Biodiesel (B99–B100)	3.22	3.38	3.46
Diesel	2.47	2.76	3.03

2. Raw Materials for Biodiesel Production

2.1. Parametric Effects for Biodiesel Production

In the biodiesel production process, many parameters can affect the yield. Examples include reactor type, agitation speed, reaction time, temperature, catalyst type and concentration, solvent-to-oil ratio, solvent type, and types of raw materials. Table 6 summarises some of the important parameters which have been put forward by previous studies and can be used as guidelines for future studies. Table 6 also shows that the most commonly-used solvent and catalyst are methanol and NaOH, respectively. According to Ejikeme et al. [46] and Leong et al. [47], NaOH is well-accepted by biodiesel producers because of its low price, corrosivity, and temperature requirements, in addition to a high conversion rate. These properties are especially true for vegetable oils. On the other hand, although short-chain alcohols like ethanol, methanol, butanol, and amyl alcohol can be applied as solvents, methanol is the most favoured due to its greater polarity, easy recovery, and cheapness, apart from being able to facilitate higher reaction rates [48,49].

Additionally, the selection of the processing parameters, especially solvent and catalyst types, is mainly influenced by the types of raw materials because different raw materials consist of different types of components such as free fatty acids (FFAs), contaminants, etc. [50,51]. This can be observed from a study reported by Halim and Kamaruddin [52], who compared the biodiesel production using palm oil and waste cooking oil. They stated that the production yield from waste cooking oil was lower than palm oil due to the high amount of water content which resulted in substrate hydrolysis and hence reduced the yield [53,54]. Thus, apart from the cost and availability of raw material, many other factors related to the raw material selection need to be considered to ensure a high yield and quality of biodiesel.

Table 6. Important parameters for transesterification/esterification process for producing biodiesel.

Parameters/References	[55]	[56]	[57]	[47]
Raw material	Waste frying oil	2-ethyl hexanoic acid	Soybean oil	Vegetable oil
Type of solvent	Methanol	Ethanol	Methanol	Methanol
Solvent to oil ratio	6:1	4:1	9:1	9:1
Type of catalyst	NaOH	Non-catalysed	NaOH	NaOH
Catalyst concentration	- *	nil	0.2 wt %	0.75 wt %
Temperature (°C)	55 ± 2	25	50	64
Reaction time (s)	3600	30	5400	60
Agitation speed (rpm)	700	- *	600	- *
Condition (type of reactor)	Shake flask	Y-shape micro-reactor	Stirred tank reactor	Ultrasonic tubular reactor
Initial raw material amount	200 mL	- *	200 g	250 mL

* Not specified.

2.2. Types of Raw Materials

Vegetable oil has been identified as the best raw material due to its sustainability, renewability, high-energy content, and energy security, which are almost similar to the petro-diesel [58]. Biodiesel produced from vegetable oils also very much alike to regular diesel, which can be utilised as a fuel blend or substitute. Moreover, various studies have been performed to explore other potential and alternative (relatively cheap) raw materials aiming to reduce production cost, such as non-edible oils [59–61], microbial lipid and cellular biomass [62,63], animal waste and fat [64,65], waste cooking oil [66–68], municipal waste and sewage sludge [50,69], rice straw and bran [70,71], and grease waste [72,73]. Although the use of various wastes could mitigate harmful environmental problems, the reaction processes could lead to the side formation of soaps, low production quality and yield, complicated downstream processes, and difficulty in the recovery of the glycerol formed, especially when homogeneous alkaline catalysts are applied [74–76]. This is due to the presence of a high amount of FFAs, contaminants, and water content in the waste materials [77].

On top of that, Ribeiro et al. [78] stated that the initial FFAs content could have a dominant effect on the biodiesel production when alkaline catalysts are applied. Besides, it has been highlighted that when the concentration of FFAs is high, the mass production is reduced, and the formation of soap is favoured. In fact, alkali-catalysed transesterification could be only performed when the FFAs content is less than 3%, whereas acid-catalysed reaction is preferable for raw materials containing high FFAs, which are low in grade and cost-effective. Additionally, when dealing with high FFAs raw materials (>3%), a two-step transesterification process is employed. This technique involves an acid-catalysed reaction as the first step to esterify the FFAs to fatty acids methyl esters (FAMEs) followed by the second step using the alkali-catalysed transesterification process. It has been reported that the two-step process using alkali-catalysed reaction in both steps can maximise the overall yield at room temperature. Thus, the proper FFAs level in the raw materials should be between 0.5% and 3% for alkali-catalysed transesterification to achieve the desired conversion rate [79].

Table 7 summarises the list of raw materials utilised in the transesterification process together with their percentage of fatty acid composition [44,48,64,65,69,80–91]. The C_{16} and C_{18} fatty acids are the major components used for producing biodiesel. Palmitic and stearic acids are some examples of saturated fatty acids, while oleic, linoleic, and linolenic acids are the examples of unsaturated fatty acids.

Table 7. Percentage of fatty acids in various raw materials [44,48,64,65,69,80–91].

Sources	% (wt) Palmitic ($C_{16:0}$)	% (wt) Stearic ($C_{18:0}$)	% (wt) Oleic ($C_{18:1}$)	% (wt) Linoleic ($C_{18:2}$)	% (wt) Linolenic ($C_{18:3}$)
Edible oils					
Palm oil	45	4	39	11	- *
Soybean	7–14	1.4–5.5	19–30	44–62	4–11
Sunflower	3–10	1–10	14–35	55–75	<0.3
Rapeseed	2.5–6.5	0.8–3.0	53–70	15–30	5–13
Corn	8–10	1–4	30–50	3456	0.5–1.5
Coconut	7–10	1–4	5–8	1–3	- *
Non-edible oils					
Rubber seed	6.47–9.9	6.6–9.9	12.8–24.95	18.87–37.59	7.97–18.23
Kapok seed	19.2	2.6	17.4	39.7	1.5
Castor	1.1	1.0	3.3	3.6	0.32
Citrus seed	26.9	4.62	25.55	37.65	3.80
Neem	18.1	18.1	44.5	18.3	0.2
Jatropha curcas	10–17	5–10	36–64	18–45	2.4–3.4
Cotton seed	21.4–26.4	2.1–5.0	14.7–21.7	46.7–58.2	0.0
Animal oils and fats					
Chicken fat	19.8	6.1	34.6	30.9	2.9
Beef tallow	24.8	20.6	46.4	2.7	0.0
Fish waste (oil)	21.6	4.1	17.3	1.7	2.9
Lamb meat (fat)	10.1	6.0	35.0	36.0	- *
Microbial lipid					
Microalgae (*Scenedesmus* sp.)	10.8–16.7	2.3–2.6	7.8–14.9	6.8–8.3	15.4–25.0
Algae (*Chlorella* sp. NJ-18)	24.53–36.37	0.98–2.06	13.57–17.19	33.7–40.77	11.32–18.46
Fungi (*Aspergillus terreus*)	20.1–36.0	10.7–23.6	30.1–41.3	8.7–23.3	0.1–0.6
Yeast (*Yarrowia lipolytica*)	2.8–24.1	4.6–7.7	3.5–38.6	2.7–14.6	- *
Cellular biomass (yeast)	24.3–33.0	1.0–7.7	54.6–55.5	1.6–58.0	0.0–2.4
Waste cooking oil	24.6	18.4	46.0	3.9	0.3
Sewage sludge	27.4–49.4	8.3–15.8	18.3–39.6	0.6-7.2	- *

* Not specified.

According to Katre et al. [84], the raw material used for producing biodiesel should present a large amount of long-chain monounsaturated fatty acids (MUFAs) and a small amount of polyunsaturated fatty acids (PUFAs) containing $\geq$4 double bonds. Biodiesel produced through the transesterification of these types of fatty acids show numerous advantages over petro-diesel such as low emissions of CO, CO_2, hydrocarbons, and unwanted particles. However, such biodiesel has several problems including low cetane number, poor cold flow properties, high viscosity, and low oxidative stability [92,93]. In contrast, long chain and saturated fatty acids give a high cetane number value that increases along with the fatty acids chain length and saturation. Hence, biodiesel derived from raw materials with a high amount of saturated fatty acids demonstrates better cold start and flow properties, while reducing NOx exhaust emissions [85,94].

3. Palm Oil as a Primary Source for Biodiesel Production

3.1. Historical Perspective

Among all existing raw materials, palm oil presents a high amount of palmitic and oleic acids that have been well known as the most suitable sources for biodiesel production. Owing to the geographical factor, each region currently prefers to utilise different sources such as soybean oil in the USA, Argentina, and Brazil, rapeseed oil in EU, and palm oil in most countries in Asia [95,96]. Several studies have highlighted the economic feasibility of palm oil as a primary raw material. For instance, Yusuf et al. [96] reported that the price of palm-biodiesel produced in Malaysia is still competitively priced in the EU. Meanwhile, Shahbazi et al. [97] revealed that the price of palm oil originated from Malaysia can compete with the domestic cultivated oil crops price in the Middle East. Furthermore, palm oil possesses significant advantages due to its high oil content [98,99] with low market price as tabulated in Table 8, abundant resources and high production capacity, accounted for one-third of the total vegetable oil production worldwide, and needs a minimal plantation area compared to other oil crops [96–101]. In addition, palm oil is a type of perennial crop unlike other oil sources, and its production is continuous throughout the year [102–104]. Moreover, palm oil is the most versatile vegetable oil due to its numerous uses in various industries [105].

Table 8. Oil content and price for various raw materials.

Type of Oils	Estimated Oil Content (kg oil/ha) [98,99]	Price (USD/ton) as May 2018 [106]
Palm oil	5000	660.00
Soybean	375	793.00
Rapeseed	1000	812.00
Coconut	2670–3310	1029.00
Sunflower	800	782.00
Peanut	890	1316.00

Palm oil originated from West Africa; but, since the late of 20th century, most palm oils plants are planted in Southeast Asia. In the middle of the 15th century, palm oil was utilised as a food source by European explorers to West Africa. During the British industrial revolution in the 18th century, the demand for palm oil increased for candle-making and as a lubricant for machines [105,107]. Two main products of its fruits are kernel oil from the kernel within the nut and oil from the outer mesocarp [99,103]. According to Demirbas [108], the fatty acid content is the major difference between both products. The oil from outer mesocarp is mainly rich in palmitic and oleic acids (about 50% saturated fat) that are very beneficial for biodiesel production, whereas palm kernel oil is rich in lauric acid (more than 89% saturated fat).

Most of the main producers of palm oil such as Malaysia and Indonesia (who supply approximately 80–85% of global capacity) have extensively developed several processes to convert palm oil, its by-products and mill effluent into biodiesel [99,103,104,109–111]. For instance, in Malaysia, the Malaysian Palm Oil Board (MPOB) is launched since the 1980s and becomes the forefront of palm-biodiesel research and development. The MPOB has successfully established several methods to produce methyl esters for biodiesel from crude palm oil (CPO) and its by-products [99]. Additionally, palm-biodiesel has become more attractive since, based on the current practices in the Malaysian palm oil industry, the use of palm-biodiesel can typically contribute to GHG emissions saving of 50–70% compared to petro-diesel [112].

3.2. Benefits and Characteristics of Palm-Biodiesel

Together with MPOB, Mercedes-Benz, and Cycle & Carriage in June 1990 until July 1995, Choo et al. [109] recorded a comprehensive field investigation using palm-biodiesel as a diesel fuel on 30 Mercedes-Benz buses with OF 1313 chassis and OM 352 engines. Each bus managed to cover ranges of up to 300,000 to 351,000 km. Their study found that the OF 1313 with OM 352 engines could be operated well with neat or blended palm-biodiesel although the engines are designed for petro-diesel (no modification required). This applies to the long-term engine operation and engine performance, which can be translated to other direct-injection engine modules. Besides, they found that the engines studied were observed with smooth and no knocking sound when starting. Within the mileage recommended by the manufacturer, the engine oil was seen in good condition, suggesting its practical usability. Moreover, much cleaner exhaust emissions were recorded with normal carbon build-up in the engine nozzles and comparable fuel consumption over petro-diesel. On top of that, the palm-biodiesel did not produce explosive vapour due to the higher flash point. Nevertheless, it demonstrated a reaction with the binding material in cement floors apart from attacking hoses and seals, which are of low-grade rubber and plastic products.

Various studies have been conducted to compare the biodiesel production from palm oil with other types of raw materials. Likozar and Levec [113] examined the transesterification of various oils into biodiesel. They discovered that soybean oil achieved the highest overall FAME conversion rate during the mass transfer-controlled stage due to high initial diglyceride content. However, as far as the chemical equilibrium was concerned, the highest final conversion was determined when palm oil was used, which is related to the larger extent of triglyceride transesterification. Other than that, palm oil is also known as a good raw material as the biodiesel has the same properties as regular petro-diesel [114]. Additionally, Talukder et al. [115] applied a two-step esterification process using CPO for producing biodiesel and discovered 98% biodiesel yield within two hours reaction period.

Based on Table 9, biodiesel produced from palm oil displayed better properties compared to other types of biodiesel especially regarding cetane number and iodine value [48,84,86,94,102,116,117]. One of the most important properties of fuel is cetane number. High cetane number implies a short ignition delay that can affect the quality of combustion [94]. Higher cetane number represents a significant advantage especially concerning clean emissions and engine performance. Palm-biodiesel having a high cetane number is crucial to ensure the biodiesel-fuelled engines will operate smoothly with less noise [118]. Several other important properties include kinematic viscosity (that affects the flow, spray, atomization, and combustion process), iodine value (indicates the degree of saturation, thus affecting the melting points, oxidative stability, and storage quality), saponification number (represents the amount of fatty acids that can promote the formation of soap), and higher heating value (depends on the iodine value and saponification number).

Table 9. Main fuel-related properties of biodiesel produced from various raw materials [48,84,86,94,102,116,117].

Type of Biodiesel	Kinematic Viscosity (40 °C; mm^2/s)	Iodine Value	Cetane Number	Saponification Number	Higher Heating Value
Petro-diesel	2.5–5.7	- *	45–55	- *	42–44.3
Palm oil	4.42–4.76	35–61	59.9–62.8	186–209	37.2–39.91
Soybean	4.08–4.42	117–143	37–52	201	37.3–39.66
Rapeseed	4.59–5.83	94–120	37.6–56	- *	37.3–39.9
Corn	3.39–4.36	103–140	55.4–59	202	39.87–41.14
Sunflower	4.38–4.90	110–143	45–51	200	37.5–39.95
Peanut	4.42–5.25	67.45	54	200	39.7
Cotton seed	4.0–9.6	90–119	41.2–59.5	204	37.5–41.68
Jatropha curcas	3.7–5.8	92–112	46–55	177–189	42.67
Fungi	4.52–4.69	54.81–91.50	56.22–61.24	190–217	39.63–40.49
Yeast	3.6–6.44	37.8–65.7	50.8–59.0	168.5–190.81	36.77–41.25
Tallow	- *	126	59	218–235	- *

* Not specified.

Nursal et al. [119] observed the performance of engine and characteristics of exhaust gas emissions for three types of biodiesel derived from CPO, waste cooking oil (WCO), and *Jatropha curcas* oil (JCO) in a marine auxiliary diesel engine. The study utilised 5% (v/v) blending ratio with 0%, 50%, and 90% load conditions throughout the engine speeds of 800, 1200, 1600, and 2000 rpm. Their study found that the overall engine performance of palm-biodiesel was enhanced, the brake thermal efficiency was slightly improved, and the brake specific fuel consumption and exhaust gas emissions were reduced compared to petro-diesel. In addition, the reduction of CO, CO_2, and HC by palm-biodiesel as well as slight increment in CO_2, NOx, and HC by JCO-biodiesel were observed in the study.

Furthermore, Vieira da Silva et al. [120] carried out another study and recorded a significant decrease in NOx emissions from palm-biodiesel compared to WCO-biodiesel, with lower or similar emissions to petro-diesel when blended with 20% and 50% of palm-biodiesel. Moreover, it was seen by Abu-Hamdeh and Alnefaie [121] that petro-diesel gave higher emissions compared to that of B10, B30, and B50 at various torques and constant engine speed. Meanwhile, in a reduced steady-state emissions test, Ng et al. [122] performed a study using constant speed and load values that represent on-road driving condition and reported a 5% decrease in NOx emissions for B100. Sharon et al. [123] also reported that palm-biodiesel had presented better results compared to other types of biodiesel as shown in Table 10 [43,124,125].

Table 10. Comparison between different types of biodiesels and petro-diesel used for compression ignition engine [43,124,125].

Parameters	Used Palm-Biodiesel	Mahua-Biodiesel	Jatropha-Biodiesel
Brake thermal efficiency	Decrease 7.26%	Decrease 13%	Decrease 7.0%
Brake specific fuel consumption	Increase 14.55%	Increase 20%	Increase 29%
Emissions of CO	Decrease 52.9%	Decrease 30%	Increase 37.77%
Emissions of smoke	Decrease 19%	Decrease 11%	Increase 26%
Emissions of hydrocarbon	Decrease 38.09%	Decrease 35%	Increase 65.43%

Besides, it was observed by Choo et al. [109] that palm-biodiesel displayed very good storage properties with slight degradation in the fuel characteristics. However, the fuel colour changed from orange to light yellow after storing for more than six months. The change in colour can be explained by the breakdown of carotenes in the methyl esters. Moreover, it was depicted that palm-biodiesel presented high flash point, indicating good properties for storage and transportation with a minimum product yield of 96.5%, which complied with the European Standard on Biodiesel (EN14214). Furthermore, a patented technology was reported in 2002 to solve the palm-biodiesel pour point problem (the temperature of +15 °C means the product can only be used in tropical countries), thus palm-biodiesel became a more versatile product. As a result, the palm-biodiesel produced with low pour points (winter grade with a temperature from −21 to 0 °C) successfully met the seasonal requirements and can now be utilised by temperate countries users. Additionally, Choo et al. [126] added that low pour point palm-biodiesel demonstrated comparable fuel properties to petro-diesel, besides having good low-temperature flow characteristics.

In short, to be used as a raw material for producing biodiesel, the targeted vegetable oils must be available at a competitive price. It is apparent that most biodiesel producers agree about the significant potential of palm oil to meet this criterion with its broad applications. In fact, palm oil has been noted as the most price efficient oil in its production cost among other vegetable oils and can be easily supplied by replanting the plant with the minimum land requirement, fertiliser, water, and pesticide [111,127]. Furthermore, the productivity, efficiency, and yield factors of the palm oil have made it preferable than other oils and fats [103,111]. When industrialists are considering vegetable oils as renewable sources for biodiesel production, palm oil will be prominent among other types of vegetable oil to meet the expanding demand for greener and cleaner energy. Various studies have been conducted using different raw materials and synthesis routes to evaluate the sustainability of palm-biodiesel by comparing it with other types of biodiesel. For example, Kurnia et al. [128] carried out a sustainability analysis on biodiesel and suggested that more studies should be done with innovative ideas to enhance the properties of biodiesel so that environmental and social impacts could be minimised besides making it more compatible with the existing diesel engines.

4. Prospects and Directions of Palm-Biodiesel

Palm-biodiesel seems to be prospering, with enormous interest in other countries. Ashnani et al. [127] and Johansson [129] found that palm-biodiesel can secure the energy supply, preserve the environment, and develop the rural regions particularly the palm oil producers such as Malaysia, Indonesia, Colombia, and Thailand by not relying on petro-diesel. Besides, producing palm-biodiesel can give social advantages that include creating new job opportunities, accelerating social development, and improving living standards for the community that work in palm tree farms.

4.1. Environmental Impact

The increment interest and use of palm-biodiesel have resulted in increasing concern on environmental impact of palm tree cultivation as well as a food versus fuel dilemma [130,131]. Moreover, the expansion of new palm tree farms to meet recent demand has triggered several issues that have been presented by many studies. Mukherjee and Sovacool [104] stated that, although the expansion of palm tree plantation is linked with deforestation and diminishes the biological habitat, the specific forestry impact from increased palm-biodiesel production remains inconclusive. This is because the spread of palm tree plantations is mainly due to the increasing food and industry demands. Nevertheless, Ashnani et al. [127] and Tan et al. [132] argued that the purpose of expanding new palm tree farms is to substitute the old plantations for a better economic revenue and not to destroy the biodiversity of the forest. Tan et al. [132] further added that sustainable development in palm tree plantation and production in the country could be strengthened if environmental-friendly measures are taken including the prohibition of burning operation, conservation of wildlife, minimisation and utilisation of waste, and integration of post management system. Kiss et al. [98] also highlighted that palm tree plantation at deforested areas at the Brazilian Amazon not only causes no damage to the plant diversity but also helps in recovering the degraded areas and offers new alternative plantation zones.

Furthermore, palm tree farms are the artificial green forests with timber and fibre which also function like the native forests but in different ways. It was discovered that palm tree farms could act as a more efficient carbon sink than rainforests, which indicates an area of dry mass that can absorb harmful GHG. Every hectare of palm tree farm assimilates up to 64.5 tonnes of CO_2 annually compared to only 42.2 tonnes for the original rainforest [127]. Palm tree farms also assimilate 44 tonnes of dry matter/ha/year compared to 25.7 tonnes by the original rainforest [99]. Moreover, a mitigation plan had been drawn to ensure carbon balance and GHG emissions due to deforestation for palm tree farms, which include increasing the use of organic fertilisers, planting on degraded land or with low biomass accumulation, and producing biochar at the time of replanting [133].

Palm oil had also been certified with a crop-specific sustainable certification standard by the Roundtable on Sustainable Palm Oil (RSPO) organisation [98]. One of the most important RSPO criteria is "*no primary forests or areas which contain significant concentrations of biodiversity (for example endangered species) or fragile ecosystems, or areas which are fundamental to meet the basic or traditional cultural needs of local communities (high conservation value areas) can be cleared*" [134]. Alternatively, clearing more land for palm tree farms can be avoided by cloning enhanced breeds of palm tree, which have a high oil yield and short maturity periods [37]. Thus, all these initiatives will ensure that the negative impacts due to the expansion of palm tree farms can be minimised.

4.2. Food vs. Fuel

Meanwhile, several social movements and non-governmental organisations (NGOs) have claimed that the use of edible oils for biodiesel production as the major factor of the global food market price increments. At present, evidence that biodiesel leads to food price increases is only circumstantial. Instead, many other reasons have been cited to have significantly caused the increment in price such as the law of supply and demand, increased production cost, fast growth of the global population, natural disasters, increased price of other oils (soybean and rapeseed oils), income growth, climate change, and political instability [37,135]. Koizumi et al. [136] highlighted that the price changes for edible palm oil in Malaysia and Indonesia caused by an increase in biodiesel demand are weak. Additionally, various studies on advance planting strategies, specialised fertilisers, and advanced crop biotechnology as well as cloning have been proposed to improve the palm oil production in an environmental-friendly and economical approach to guarantee an equal role of palm oil in the food and fuel supply for a sustainable prospect [37]. Due to that, the giant producers of palm oil such as Indonesia and Malaysia have agreed to implement a certain limit amount of palm oil resources to be used as biodiesel to ensure that the food supply is not disrupted. The fast growth of palm tree farms in Indonesia and Malaysia is mainly influenced by the expanding demand for industrial and food processes in Asia such as China and India, instead of the need for biodiesel production [135].

4.3. The Prospect of Palm Oil By-Products and Mill Effluent for Biodiesel Production

Although the effects of biodiesel on the global food market prices could be considered as non-significant, the focus must be put on non-edible sources rather than the edible sources to ensure the social acceptance of biodiesel. Concerning this, the prospect and direction of palm-biodiesel have been expanded to utilising by-products and mill effluent from the palm oil industry such as waste palm oil (WCO), palm fatty acid distillate (PFAD), sludge oil, fatty acid residue, palm stearin, palm olein, residual oil from empty fruit bunch (EFB), residual oil from palm decanter cake (PDC), residual oil from palm oil mill effluent (POME), residual oil from spent bleaching earth (SBE), and CPO industrial liquid waste. Table 11 summarises various studies on the use of by-products and mill effluent from palm oil industry in producing biodiesel.

The palm oil industry produces various types of wastes in a large quantity either in the liquid or solid forms [99]. In fact, only 10% of the total biomass obtained from palm oil farm is converted into edible oil, while the other 90% are disposed-off as waste materials [128,137,138]. In specific locations such as Indonesia, the biomass produced from the palm oil industry is seven times higher than that of other timber industries [128,139]. For instance, Herjanto and Widana [140] stated that an overall palm oil refining process could produce 73% of olein, 21% of stearin, 5% of PFAD, and 0.5% of effluent. Disposing of those wastes will create serious problems for the environment and community. For example, SBE is usually disposed as a waste by dumping it in landfills without any attempts to recover the oil, thus posing a serious threat to the environment through fire and the release of pollution hazards. Hence, it has been suggested that the oil in SBE is recovered and reused as an alternative energy source, which in turn could reduce the cost associated with refining processes [141,142].

Other than that, POME is one of the major causes of industrial oily wastewater, which is generated as a by-product during palm oil processing. Most of the palm oil factories use conventional ponding systems to treat POME that requires a long treatment period and a large area. Instead of being left in the pond, POME could become an attractive natural source for biodiesel production since the oil concentration in POME ranges between 4000 and 8000 mg/L [143–145]. Although those wastes can be efficiently treated by available treatment technologies to meet the standard discharge limits, it also can be used as a cheaper raw material for producing biodiesel together with the importance of highlighting the global sustainability challenges. In agreement with the research necessity, various research has been performed using different processing routes to produce biodiesel from palm oil by-products and mill effluent as summarised in Table 11.

The biodiesel yield and characteristics vary depending on the raw materials and methods used. The utilization of palm oil by-products and mill effluent in biodiesel production generates numerous benefits in the biodiesel industry especially in terms of reduction in production cost, maintenance of the biodiesel quality and yield, and environmental protection for a better quality of social life as tabulated in Table 12. These studies have been successfully carried out at the laboratory scale that further proved their various potentials to be applied to the biodiesel industry. Although the palm oil by-products and mill effluent are not currently employed for a large-scale biodiesel production, it is believed that this proposed area of study is useful for the sustainable biodiesel production as the results of these studies could open new opportunities in finding various alternative raw materials through an oil recovery from low-cost and available sources.

Apart from that, wastes from palm oil industry not only can be directly utilised as a feedstocks for producing biodiesel but also for other purposes. For example, Lam and Lee [146] utilised POME as a cost-efficient nutrient medium for microalgae cultivation which could produce biodiesel and bioethanol. Besides, lipid from microalgae has been recognised as a good feedstock for biodiesel production as the yield produced is approximately 100 times higher than those produced from a hectar of oilseeds. Furthermore, various studies have been done to utilise the solid wastes like EFB into efficient solid catalysts that are suitable for producing biodiesel [147].

Table 11. Production of biodiesel from palm oil by-products and mill effluent.

Raw Material	References	Method/Reactor	Alcohol	Catalyst	Time (min)	Temp. (°C)	Stirring (RPM)	Yield (%)	Highlights
Waste palm oil (frying oil)	[148]	Flask	Ethanol	HCl & H_2SO_4	180	90	nil	- *	Lower sulphur content & higher flash point.
Palm fatty acid distillate	[147]	Flask	Methanol	SPSC-SO_3H	120	60	600	97.8	Good reusability and better catalyst activity.
Palm fatty acid distillate	[149]	Semi-batch reactor	Methanol	Non-catalytic	- *	60	- *	91.2	Mainly contains palmitic (33.5%) & oleic (41.6%) acids.
Palm fatty acid distillate	[150]	Flask	Methanol	H_2SO_4	90	70–80	- *	93.9	Mainly contains 45.6% palmitic and 33.3% oleic acids. Product follows the ASTM standard.
Palm fatty acid distillate	[151]	Flask	Methanol	TPA/$Cs_{1.0}$/Nb_2O_5	480	65	700	90.0	Product properties are same with palm-biodiesel and follow ASTM D6751 and EN 14214 standard.
Sludge oil	[152]	Flask	Methanol	EFB ash & Alum	180	65	- *	86.17	The conversion yield is higher than CPO.
Sludge oil	[153]	Flask	Nil	NaOH & Deep eutectic solvent	60	80	400	83.19	Mainly contains palmitic (34.5%) & oleic (41.89%) acids.
Sludge oil	[154]	Batch reactor	Methanol	H_2SO_4	120	65	- *	- *	Achieved 96% of FFA conversion.
Sludge oil	[155]	Flask	Ethanol	*C. cylindracea* lipase	1440 (24 h)	40	250	62.3	POME based lipase shows a promising potential to reduce the production cost and environmental pollutions.
Sludge oil	[156]	Flask	Methanol	Zr-rice husk ash	240	60	500	- *	The highest FFA conversion was 83.1%.
Sludge oil	[157]	Flask	Methanol	*Imperata cylindrica* sp.	60	65	- *	80.0	The properties of B5 biodiesel produced within the standard limit with less smoke emissions when testing using diesel engine.
Fatty acid residue	[158]	Batch reactor	Ethanol	H_2SO_4	60	130	500	>90.0	Reaction inhibited by the presence of water (soap formed).
Palm stearin	[159]	Flask	Methanol	NaOH	* focus on performance and emissions: reduction in OC, HC, and smoke opacity.			98.1	The properties of B40 biodiesel within the standard limit.
Used palm olein/glycerol	[160]	Batch reactor	Methanol	Non-catalytic	18–20	400	nil	80.0	The used palm olein oil has high FFAs content (4.56%).

Table 11. *Cont.*

Raw Material	References	Method/Reactor	Alcohol	Catalyst	Time (min)	Temp. (°C)	Stirring (RPM)	Yield (%)	Highlights
Palm olein	[161]	Supercritical process	Methanol	Non-catalytic	20	350	nil	94.96	The transesterification required harsh conditions.
Palm olein	[162]	Batch reactor	Methanol/Ethanol	KOH	60	50	700	98.1	Follow the EN14214 standard and comparable with petrol-diesel.
Residual oil from POME	[163]	Flask	Methanol	Crude lipase	2160 (36 h)	35	200	92.07 ± 1.04	8% of oil was recovered from POME. Biodiesel produce has high cetane number (59–60) and cloud point (10–13 °C).
Residual oil from POME	[164]	Batch reactor	Methanol	Non-catalytic	300	230	500	77.64	Biodiesel produced mainly contains 45.45% of palmitic acid and 50.84% of oleic acid.
Residual oil from palm decanter cake (PDC)	[165]	Flask	Methanol	Sulfonating rice husk ash	300	120	- *	70.2	11.3% oil recovered from PDC.
Residual oil of spent bleaching earth (SBE)	[166]	Batch reactor	Methanol	H_2SO_4 & NaOH	90	65	730	84.5	SBE contains 20–30% oil. Biodiesel has heater efficiency of 48% and specific energy of 6738 kJ/kg.
Residual oil of spent bleaching earth (SBE)	[141]	Flask	Methanol	Cocoa pod ash (CPA) & KOH	120	100	- *	86.0 & 81.20	16% residual oil recovered from SBE. The CPA is better catalyst than KOH. All fuel properties examined fell within the ASTM specification for B100.
Liquid waste from CPO industry	[167]	Flask	Methanol	H_2SO_4 & CaO	120	60	- *	- *	Liquid waste of CPO contains 0.5–1% of oil.
Residual oil from EFB	[6]	Continuous reactor	Nitrogen gas	MgO	- *	500	- *	60.10	Pyrolysis method had been used. The catalytic cracking produced higher yield.
Pyrolytic oil from palm oil kernel shell	[77]	Quartz reactor	Ethanol	H_2SO_4	* focus on the product quality: pH, density, and calorific value.				Product has better pH and calorific value without undesirable compounds.

* Not specified.

Table 12. Benefits of utilization palm oil by-products and mill effluent in biodiesel production.

Areas	Benefits
Production cost	✓ The utilization of PFAD shows around 20% to 30% lower in production cost as compared to the refined vegetable oil in the conventional processing route [168]. ✓ The raw materials are readily available, abundant in quantity, and cheaper price. ✓ These results support the potential and competitiveness of the proposed raw materials in the industry.
Product yield and quality	✓ The production yield obtained a higher rate than 60% from the raw materials with high fatty acids content. ✓ The high amount of FFAs could be reduced through esterification process without major modification, in which they have successfully reduced 93% of FFAs content to less than 2% [149]. ✓ Biodiesel produced showed similar properties with palm-biodiesel and follow the international standards (ASTM D6751 and EN 14214).
Environment and social	✓ Waste utilization will improve the environment quality. ✓ It also can reduce the releasing and emissions of hazardous materials from the waste. ✓ These practices will provide better living quality and standard for the people.

While producing the biodiesel from palm oil by-products and mill effluent is able to give many benefits to various parties, more studies are yet to be conducted to: (i) design an efficient conversion method to produce biodiesel with high yield and quality using minimum production cost and impacts on the environment; (ii) develop a comprehensive strategy to connect and transport the wastes from their location and production facilities; (iii) conduct a detailed study and simulation using computational approach to understand the reaction possibilities and optimise its production rate; (iv) perform a complete field test using biodiesel produced from various types of palm oil by-products and mill effluent to determine their performance and effects to the engine; and (v) implement the improvement gained from the sustainability studies (using life cycle analysis) to create an affordable, environmental-friendly, and profitable biodiesel production using palm oil by-products and mill effluent.

5. Future Challenges

5.1. Sustainability and Feasibility of Palm-Biodiesel Production

The World Commission on Environment and Development (WCDE) defined sustainable development as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". In 1992, the United Nation (UN) highlighted the significance of sustainable development and declared that "the right to development must be fulfilled to equitably meet developmental and environmental needs of present and future generations". Meanwhile, in 2002, the World Summit on Sustainable Development established the target of sustainable development as the "access to reliable, affordable, economically viable, socially acceptable, and environmentally sound energy services and resources" [169,170].

Therefore, the application of sustainable energy usage involves a wise utilisation of energy produced by clean technologies and derived from renewable sources, leading to no damage to the environment and society. In short, sustainable palm-biodiesel production comprises legal and economic viable, appropriate to the environment, and is beneficial for the development of society and community.

5.2. Economic Viewpoint

From the economic perspective, the utilisation of bioenergy like biodiesel may not be as economically attractive as using conventional energy (petro-diesel). However, this should not prevent the widespread use of biodiesel as the concerns about depletion of the fossil resources and environmental protection must be prioritised. The continuous expansion of the biodiesel industries has been acknowledged and promoted by renewable fuel policies including subsidies, incentives, mandates, and taxes in various countries such as the USA, EU, Malaysia, Indonesia, and Brazil. Moreover, the global biofuel market has been estimated to approximately grow at 5.4% CAGR (compound annual growth rate) during the year of 2017 to 2024 while the capacity of biodiesel production has been expected to achieve 12 billion gallons by 2020. In 2013, the Environmental Protection Agency (EPA) set the Renewable Volume Obligation (RVO) in the yearly rulemaking under a congressional mandate that termed for the nation to utilise 36 billion gallons of renewable fuels in transportation by 2022 [171,172].

Other than that, the use of biodiesel in many other applications besides a petro-diesel substitute for transportation can enhance its economic viability. For instance, palm-biodiesel can be employed as a heating fuel in commercial and domestic boilers. It also can be used as a solvent for oleochemical industries as biodiesel exhibits better solvency power than that of petroleum-based solvent. However, the economic potential of palm-biodiesel will only be viable if the price of its primary raw material (CPO) remained at a competitive level or when sufficient subsidies are applied. Thus, it is crucial to study the utilisation of palm oil by-products and mill effluent in biodiesel production to achieve and sustain economic viability. Currently, biomass sources including palm oil by-products and mill effluent are gaining huge attention for supplying the world's energy demand and have been predicted to share by one half of the total world energy demand by 2050 [173].

5.3. Environmental Preservation

In terms of environmental preservation, the major concern on the use of petro-diesel is in the serious rising level of GHG emissions, mainly CO_2, that is correlated to global warming. Several studies have found that although CO_2 was emitted during the use of biodiesel, the net emissions of CO_2 is still estimated to be zero since it is derived from plants that require CO_2 for their growth. As highlighted by the Department of Agricultural Energy USA, the life cycle of CO_2 could be shortened by 78% using biodiesel owing to the low emissions of CO and hydrocarbons to the atmosphere. Furthermore, the utilisation of palm-biodiesel demonstrated the lowest emissions of CO_2 compared to petro-diesel and other types of biodiesel due to the lesser land, fertilisers, pesticides, and machinery used during palm tree plantation [98,108].

In addition, it has been revealed that palm trees show a very high photosynthetic rate with the ability to absorb up to 10 times more CO_2 and emit 8 to10 times more O_2 per hectare annually compared to other crops cultivated in temperate countries [37,174]. Besides, the utilisation of palm oil by-products and mill effluent in producing biodiesel could also give a positive waste management effect on the environment. Finally, the biodiesel produced from palm oil, by-products, and mill effluent is preferred over the petro-diesel owing to its environmental advantages [141].

5.4. Social Impact

A well-planned development of palm-biodiesel industry is undoubtedly beneficial to the society and community especially in the rural areas involved with the plantation of palm trees. New palm tree plantation requires an intensive ground work and a large number of workers that will offer huge opportunities and alternative income for the community [98]. As Mukherjee and Sovacool [104] also added, in some countries like Malaysia and Indonesia, palm tree plantations are some of the major sources of employment and job providers.

Additionally, the progress and fast growth for palm-biodiesel demand and production will increase crop yields, thus discovering new applications for the agricultural products and intensifying the economic and revenue growth [99]. Consequently, new markets opportunities can be developed whether local or overseas with more employment chances created, which could provide better living quality and standards for the public. Looking at a broader benefit, it has been expected by the industry players that the palm oil-related sectors have benefitted around six million peoples around the world with many of them have been relieved from poverty [99,135,175].

6. Conclusions

The depletion of fossil resources, increased petroleum crude oil price, and awareness of environmental protection have led to increased studies and development efforts to find renewable and environmental-friendly alternative energy sources. Additionally, the current high demand for renewable energies has caused a high production of biodiesel and developed the fastest growing industry worldwide. Nonetheless, the booming of biodiesel has led to speculations and concerns on the relationship between palm-biodiesel with food supply and tropical deforestation. However, if suitable practices are employed, those speculations can be avoided, and palm-biodiesel can 'come clean'. Thus, the historical development of palm-biodiesel seemed attractive.

Palm-biodiesel has successfully existed as an efficient energy source despite being relegated for many years due to many issues and speculations. Other milestones related to the palm-biodiesel industry are the reduction of environmental impact, an increment of job opportunities, enhancement of energy security, and maximisation of waste utilisation. Besides, palm-biodiesel has been noted as a viable and practical alternative or additive to petro-diesel through its excellent characteristics such as clean-burning, nontoxicity, renewability, sustainability, and acceptability. On top of that, it also has benefits including its cheaper cost and more positive carbon benefits than other major biodiesel sources [176]. These can consequently lead to the increase in prospects for the palm-biodiesel industry.

To summarise all this, the future trends of palm-biodiesel will likely move towards the balance between market demands with the community and consumer perceptions. The exploration of alternative sources for green biodiesel production is still ongoing. This study had proposed palm oil by-products and mill effluent as the future raw materials for biodiesel mainly due to their cheaper cost, availability, abundance, environmental friendliness as well as the minimum impact on food security. Few technologies have been developed with more improvements that are yet to be proposed. Several key challenges involved will offer new research potentiality to improve the product quality and solve other problems especially related to the environment. A comprehensive study is still needed to be carried out for foreseeable future.

Author Contributions: K.A.Z. responsible for writing and preparing the manuscript; M.K. responsible for reviewing and editing the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ma, F.; Hanna, M.A. Biodiesel production: A review. *Bioresour. Technol.* **1999**, *70*, 1–15. [CrossRef]
2. Venkatesan, M.; Vikram, C.J.; Naveenchandran, P. Performance and emission analysis of pongamia oil methyl ester with diesel blend. *Middle-East J. Sci. Res.* **2012**, *12*, 1758–1765. [CrossRef]
3. Adewale, P.; Dumont, M.J.; Ngadi, M. Recent trends of biodiesel production from animal fat wastes and associated production techniques. *Renew. Sustain. Energy Rev.* **2015**, *45*, 574–588. [CrossRef]
4. Atabani, A.E.; Silitonga, A.S.; Badruddin, I.A.; Mahlia, T.M.I.; Masjuki, H.H.; Mekhilef, S. A comprehensive review on biodiesel as an alternative energy resource and its characteristics. *Renew. Sustain. Energy Rev.* **2012**, *16*, 2070–2093. [CrossRef]

5. Avhad, M.R.; Marchetti, J.M. A review on recent advancement in catalytic materials for biodiesel production. *Renew. Sustain. Energy Rev.* **2015**, *50*, 696–718. [CrossRef]
6. Charusiri, W.; Vitidsant, T. Response surface methodology optimization of biofuels produced by catalytic pyrolysis of residual palm oil from empty fruit bunch over magnesium oxide. *J. Chem. Eng. Jpn.* **2017**, *50*, 727–736. [CrossRef]
7. Sani, Y.M.; Daud, W.M.A.W.; Abdul Aziz, R.A. Biodiesel feedstock and production technologies: Successes, challenges and prospects. In *Biodiesel—Feedstocks, Production and Applications*; Zhen, F., Ed.; IntechOpen: London, UK, 2012; pp. 77–101.
8. Sommani, P.; Mankong, N.; Vitidsant, T.; Lothongkum, A.W. Cracking of used vegetable oil mixed with polypropylene waste in the presence of activated carbon. *ASEAN Eng. J. Part B* **2013**, *4*, 16–24.
9. Duran, E.A.; Tinoco, R.; Perez, A.; Berrones, R.; Eapen, D.; Sebastian, P.J. A comparative study of biodiesel purification with magnesium silicate and water. *J. New Mater. Electrochem. Syst.* **2014**, *17*, 105–111. [CrossRef]
10. Stamenkovic, O.S.; Todorovic, Z.B.; Lazic, M.L.; Veljkovic, V.B.; Skala, D.U. Kinetics of sunflower oil methanolysis at low temperatures. *Bioresour. Technol.* **2008**, *99*, 1131–1140. [CrossRef] [PubMed]
11. Gashaw, A.; Getachew, T.; Teshita, A. A review on biodiesel production as alternative fuel. *J. For. Prod. Ind.* **2015**, *4*, 80–85.
12. Parkar, P.A.; Choudhary, H.A.; Moholkar, V.S. Mechanistic and kinetic investigations in ultrasound assisted acid catalyzed biodiesel synthesis. *Chem. Eng. J.* **2012**, *187*, 248–260. [CrossRef]
13. Talha, N.S.; Sulaiman, S. Overview of catalysts in biodiesel production. *ARPN J. Eng. Appl. Sci.* **2016**, *11*, 439–448.
14. Jose, M.D.A.; Cardoso, A.L. Heterogeneous tin catalysts applied to the esterification and transesterification reactions. *J. Catal.* **2013**, 1–12. [CrossRef]
15. Lotero, E.; Liu, Y.; Lopez, D.E.; Suwannakarn, K.; Bruce, D.A.; Goodwin, J.G. Synthesis of biodiesel via acid catalysis. *Ind. Eng. Chem. Res.* **2005**, *44*, 5353–5363. [CrossRef]
16. Saifuddin, N.; Samiuddin, A.; Kumaran, P. A review on processing technology for biodiesel production. *Trends Appl. Sci. Res.* **2015**, *10*, 1–37. [CrossRef]
17. Alhassan, F.H.; Yunus, R.; Rashid, U.; Sirat, K.; Islam, A.; Lee, H.V.; Taufiq-Yap, Y.H. Production of biodiesel from mixed waste vegetable oils using ferric hydrogen sulphate as an effective reusable heterogeneous solid acid catalyst. *Appl. Catal. A Gen.* **2013**, *456*, 182–187. [CrossRef]
18. De Lima, A.L.; Ronconi, C.M.; Mota, C.J.A. Heterogeneous basic catalysts for biodiesel production. *Catal. Sci. Technol.* **2016**, *6*, 2877–2891. [CrossRef]
19. Lee, A.F.; Bennett, J.A.; Manayil, J.C.; Wilson, K. Heterogeneous catalysis for sustainable biodiesel production via esterification and transesterification. *Chem. Soc. Rev.* **2014**, *43*, 7887–7916. [CrossRef] [PubMed]
20. Lee, A.F.; Wilson, K. Recent developments in heterogeneous catalysis for the sustainable production of biodiesel. *Catal. Today* **2015**, *242*, 3–18. [CrossRef]
21. Di Serio, M.; Tesser, R.; Pengmei, L.; Santacesaria, E. Heterogeneous catalysts for biodiesel production. *Energy Fuels* **2008**, *22*, 207–217. [CrossRef]
22. Sivasamy, A.; Cheah, K.Y.; Fornasiero, P.; Kemausuor, F.; Zinoviev, S.; Miertus, S. Catalytic applications in the production of biodiesel from vegetable oils. *ChemSusChem* **2009**, *2*, 278–300. [CrossRef] [PubMed]
23. Yan, J.; Zheng, X.; Li, S. A novel and robust recombinant *Pichia pastoris* yeast whole cell biocatalyst with intracellular overexpression of a *Thermomyces lanuginosus* lipase: Preparation, characterization and application in biodiesel production. *Bioresour. Technol.* **2014**, *151*, 43–48. [CrossRef] [PubMed]
24. Yucel, S.; Terzioglu, P.; Ozcimen, D. Lipase applications in biodiesel production. In *Biodiesel-Feedstocks, Production and Application*; Zhen, F., Ed.; IntechOpen: London, UK, 2013; pp. 209–250.
25. Ondul, E.; Dizge, N.; Keskinler, B.; Albayrak, N. Biocatalytic production of biodiesel from vegetable oils. In *Biofuels—Status and Perspective*; Biernat, K., Ed.; IntechOpen: London, UK, 2015; pp. 21–37. doi:10.5772/59949.
26. Ranganathan, S.V.; Narasimhan, S.L.; Muthukumar, K. An overview of enzymatic production of biodiesel. *Bioresour. Technol.* **2008**, *99*, 3975–3981. [CrossRef] [PubMed]
27. Xiao, M.; Mathew, S.; Obbard, J.P. Biodiesel fuel production via transesterification of oils using lipase biocatalyst. *GCB Bioenergy* **2009**, *1*, 115–125. [CrossRef]
28. Ghandi, K. A review of ionic liquids, their limits and applications. *Green Sustain. Chem.* **2014**, *4*, 44–53. [CrossRef]

29. Nan, Y.; Liu, J.; Lin, R.; Tavlarides, L.L. Production of biodiesel from microalgae oil (*Chlorella protothecoides*) by non-catalytic transesterification in supercritical methanol and ethanol: Process optimization. *J. Supercrit. Fluids* **2015**, *97*, 174–182. [CrossRef]
30. Qiao, B.Q.; Zhou, D.; Li, G.; Yin, J.Z.; Xue, S.; Liu, J. Process enhancement of supercritical methanol biodiesel production by packing beds. *Bioresour. Technol.* **2017**, *228*, 298–304. [CrossRef] [PubMed]
31. Sanchez, N.; Encinar, J.M.; Martinez, G.; Gonzalez, J.F. Biodiesel production from castor oil under subcritical methanol conditions. *Int. J. Environ. Sci. Dev.* **2015**, *6*, 61–66. [CrossRef]
32. Ang, G.T.; Tan, K.T.; Lee, K.T. Recent development and economic analysis of glycerol-free processes via supercritical fluid transesterification for biodiesel production. *Renew. Sustain. Energy Rev.* **2014**, *31*, 61–70. [CrossRef]
33. Andreani, L.; Rocha, J.D. Use of ionic liquids in biodiesel production: A review. *Braz. J. Chem. Eng.* **2012**, *29*, 1–13. [CrossRef]
34. Han, B.; Li, T.; Deng, R.; Xiong, X.; Chen, C. A review on Bronsted acid ionic liquids catalysts for biodiesel synthesis through transesterification. *Appl. Mech. Mater.* **2013**, *389*, 46–52. [CrossRef]
35. Liu, S.; Wang, Z.; Yu, S.; Xie, C. Transesterification of waste oil to biodiesel using Bronsted acid ionic liquid as catalyst. *Bull. Chem. Soc. Ethiop.* **2013**, *27*, 289–294. [CrossRef]
36. Liu, Y.; Lu, H.; Jiang, W.; Li, D.; Liu, S.; Liang, B. Biodiesel production from crude *Jatropha curcas* L. oil with trace acid catalyst. *Chin. J. Chem. Eng.* **2012**, *20*, 740–746. [CrossRef]
37. Lam, M.K.; Tan, K.T.; Lee, K.T.; Mohamed, A.R. Malaysian palm oil: Surviving the food versus fuel dispute for a sustainable future. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1456–1464. [CrossRef]
38. Demirbas, A. *Biodiesel: A Realistic Fuel Alternative for Diesel Engines*; Springer: London, UK, 2008.
39. Gerpen, J.V. Biodiesel processing and production. *Fuel Process. Technol.* **2005**, *86*, 1097–1107. [CrossRef]
40. Mahmudul, H.M.; Hagos, F.Y.; Mamat, R.; Adam, A.A.; Ishak, W.F.W.; Alenezi, R. Production, characterization and performance of biodiesel as an alternative fuel in diesel engines-A review. *Renew. Sustain. Energy Rev.* **2017**, *72*, 497–509. [CrossRef]
41. Demirbas, A. Progress and recent trends in biodiesel fuels. *Energy Convers. Manag.* **2009**, *50*, 14–34. [CrossRef]
42. Liennard, A.; Pioch, D.; Chirat, N.; Lozano, P.; Vaitilingom, G. Energy generation from "neat" vegetable oils. In Proceedings of the SciELO of 4th Encontro de Energia no Meio Rural, Campinas, Brazil, 28–31 October 2002.
43. Datta, A.; Mandal, B.K. A comprehensive review of biodiesel as an alternative fuel for compression ignition engine. *Renew. Sustain. Energy Rev.* **2016**, *57*, 799–821. [CrossRef]
44. Aarthy, M.; Saravanan, P.; Gowthaman, M.K.; Rose, C.; Kamini, N.R. Enzymatic transesterification for production of biodiesel using yeast lipases: An overview. *Chem. Eng. Res. Des.* **2014**, *92*, 1591–1601. [CrossRef]
45. The U.S. Department of Energy, Alternative Fuels Data Center for the USA. Available online: https://www.afdc.energy.gov/fuels/prices.html (accessed on 17 July 2018).
46. Ejikeme, P.M.; Anyaogu, I.D.; Ejikeme, C.L.; Nwafor, N.P.; Egbuonu, C.A.C.; Ukogu, K.; Ibemesi, J.A. Catalysis in biodiesel production by transesterification processes—An insight. *E-J. Chem.* **2010**, *7*, 1120–1132. [CrossRef]
47. Leong, B.S.; Rus, M.; Zafiah, A.; Hasan, S. Continuous biodiesel production using ultrasonic clamp on tubular reactor. In Proceedings of the International Conference on Mechanical Engineering Research (ICMER2013), Kuantan, Pahang, Malaysia, 1–3 July 2013; pp. 1–10.
48. Le, T.T.; Okitsu, K.; Luu, V.B.; Maeda, Y. Catalytic technologies for biodiesel fuel production and utilization of glycerol: A review. *Catalysts* **2012**, *2*, 191–222. [CrossRef]
49. Romano, S.D.; Sorichetti, P.A. Introduction to biodiesel production, in: Dielectric spectroscopy in biodiesel production and characterization. In *Green Energy and Technology*; Springer: London, UK, 2011; pp. 7–27.
50. Shahzad, K.; Nizami, A.S.; Sagir, M.; Rehan, M.; Maier, S.; Khan, M.Z.; Ouda, M.; Ismail, L.M.I.; BaFail, A.O. Biodiesel production potential from fat fraction of municipal waste in Makkah. *PLoS ONE* **2017**, *12*, 1–14. [CrossRef] [PubMed]
51. Voca, N.; Krieka, T.; Janu, V.; Ana, J.; Darko, M. Fuel properties of biodiesel produced from different raw materials in Croatia. *J. Mech. Eng.* **2008**, *54*, 232–244.
52. Halim, S.F.A.; Kamaruddin, A.H. Catalytic studies of lipase on FAME production from waste cooking palm oil in a *tert*-butanol system. *Process Biochem.* **2008**, *43*, 1436–1439. [CrossRef]

53. Azocar, L.; Ciudad, G.; Heipieper, H.J.; Navia, R. Biotechnological processes for biodiesel production using alternative oils. *Appl. Microbiol. Biotechnol.* **2010**, *88*, 621–636. [CrossRef] [PubMed]
54. Fjerbaek, L.; Christensen, K.V.; Norddahl, B. A review of the current state of biodiesel production using enzymatic transesterification. *Biotechnol. Bioeng.* **2009**, *102*, 1298–1315. [CrossRef] [PubMed]
55. Duti, I.J.; Maliha, M.; Ahmed, S. Biodiesel production from waste frying oil and its process simulation. *J. Mod. Sci. Technol.* **2016**, *4*, 50–62.
56. Zanati, E.; El Abdallah, H.; Elnahas, G. Micro-reactor for non-catalyzed esterification reaction: Performance and modeling. *Int. J. Chem. React. Eng.* **2016**, 1–12. [CrossRef]
57. Bashiri, H.; Pourbeiram, N. Biodiesel production through transesterification of soybean oil: A kinetic Monte Carlo study. *J. Mol. Liquids* **2016**, *223*, 10–15. [CrossRef]
58. Demirbas, A. Biodiesel production from vegetable oils via catalytic and non-catalytic supercritical methanol transesterification methods. *Prog. Energy Combust. Sci.* **2005**, *31*, 466–487. [CrossRef]
59. Fadhil, A.B.; Aziz, A.M.; Al-Tamer, M.H. Biodiesel production from *Silybum marianum* L. seed oil with high FFA content using sulfonated carbon catalyst for esterification and base catalyst for transesterification. *Energy Convers. Manag.* **2016**, *108*, 255–265. [CrossRef]
60. Kumar, R.; Tiwari, P.; Garg, S. Alkali transesterification of linseed oil for biodiesel production. *Fuel* **2013**, *104*, 553–560. [CrossRef]
61. Lee, H.V.; Juan, J.C.; Taufiq-Yap, Y.H. Preparation and application of binary acid-base CaO-La_2O_3 catalyst for biodiesel production. *Renew. Energy* **2015**, *74*, 124–132. [CrossRef]
62. Huang, J.; Xia, J.; Jiang, W.; Li, Y.; Li, J. Biodiesel production from microalgae oil catalyzed by a recombinant lipase. *Bioresour. Technol.* **2015**, *180*, 47–53. [CrossRef] [PubMed]
63. Wahlen, B.D.; Morgan, M.R.; Mccurdy, A.T.; Willis, R.M.; Morgan, M.D.; Dye, D.J.; Bugbee, B.; Wood, B.C.; Seefeldt, L.C. Biodiesel from microalgae, yeast, and bacteria: Engine performance and exhaust emissions. *Energy Fuels* **2013**, *27*, 220–228. [CrossRef]
64. Alptekin, E.; Canakci, M.; Sanli, H. Biodiesel production from vegetable oil and waste animal fats in a pilot plant. *Waste Manag.* **2014**, *34*, 2146–2154. [CrossRef] [PubMed]
65. Ito, T.; Sakurai, Y.; Kakuta, Y.; Sugano, M.; Hirano, K. Biodiesel production from waste animal fats using pyrolysis method. *Fuel Process. Technol.* **2012**, *94*, 47–52. [CrossRef]
66. Farooq, M.; Ramli, A. Biodiesel production from low FFA waste cooking oil using heterogeneous catalyst derived from chicken bones. *Renew. Energy* **2015**, *76*, 362–368. [CrossRef]
67. Sirisomboonchai, S.; Abuduwayiti, M.; Guan, G.; Samart, C.; Abliz, S.; Hao, X.; Kusakabe, K.; Abudula, A. Biodiesel production from waste cooking oil using calcined scallop shell as catalyst. *Energy Convers. Manag.* **2015**, *95*, 242–247. [CrossRef]
68. Tan, H.Y.; Abdullah, O.M.; Nolasco-hipolito, C.; Taufiq-Yap, Y.H. Waste ostrich- and chicken-eggshells as heterogeneous base catalyst for biodiesel production from used cooking oil: Catalyst characterization and biodiesel yield performance. *Appl. Energy* **2015**, *160*, 58–70. [CrossRef]
69. Olkiewicz, M.; Caporgno, M.P.; Fortuny, A.; Stuber, F.; Fabregat, A.; Font, J.; Bengoa, C. Direct liquid-liquid extraction of lipid from municipal sewage sludge for biodiesel production. *Fuel Process. Technol.* **2014**, *128*, 331–338. [CrossRef]
70. El Boulifi, N.; Bouaid, A.; Martinez, M.; Aracil, J. Optimization and oxidative stability of biodiesel production from rice bran oil. *Renew. Energy* **2013**, *53*, 141–147. [CrossRef]
71. Zheng, L.; Hou, Y.; Li, W.; Yang, S.; Li, Q.; Yu, Z. Biodiesel production from rice straw and restaurant waste employing black soldier fly assisted by microbes. *Energy* **2012**, *47*, 225–229. [CrossRef]
72. Li, A.; Ngo, T.P.N.; Yan, J.; Tian, K.; Li, Z. Whole-cell based solvent-free system for one-pot production of biodiesel from waste grease. *Bioresour. Technol.* **2012**, *114*, 725–729. [CrossRef] [PubMed]
73. Yan, J.; Li, A.; Xu, Y.; Ngo, T.P.N.; Phua, S.; Li, Z. Efficient production of biodiesel from waste grease: One-pot esterification and transesterification with tandem lipases. *Bioresour. Technol.* **2012**, *123*, 332–337. [CrossRef] [PubMed]
74. Atadashi, I.M.; Aroua, M.K.; Abdul Aziz, A.R.; Sulaiman, N.M.N. The effects of water on biodiesel production and refining technologies: A review. *Renew. Sustain. Energy Rev.* **2012**, *16*, 3456–3470. [CrossRef]
75. Da Silva, C.; Vladimir Oliveira, J. Biodiesel production through non-catalytic supercritical transesterification: Current state and perspectives. *Braz. J. Chem. Eng.* **2014**, *31*, 271–285. [CrossRef]

76. Ghoreishi, S.M.; Moein, P. Biodiesel synthesis from waste vegetable oil via transesterification reaction in supercritical methanol. *J. Supercrit. Fluids* **2013**, *76*, 24–31. [CrossRef]
77. Aziz, S.M.A.; Wahi, R.; Ngaini, Z.; Hamdan, S.; Yahaya, S.A. Esterification of microwave pyrolytic oil from palm oil kernel shell. *J. Chem.* **2017**, 1–8. [CrossRef]
78. Ribeiro, A.; Castro, F.; Carvalho, J. Influence of free fatty acid content in biodiesel production on non-edible oils. In Proceedings of the 1st International Conference WASTES: Solutions, Treatments and Opportunities, Guimarães, Portugal, 12–14 September 2011.
79. Cunha Jr., A.; Feddern, V.; De Pra, M.C.; Higarashi, M.M.; De Abreu, P.G.; Coldebella, A. Synthesis and characterization of ethylic biodiesel from animal fat wastes. *Fuel* **2013**, *105*, 228–234. [CrossRef]
80. Ahmad, J.; Yusup, S.; Bokhari, A.; Kamil, R.N.M. Study of fuel properties of rubber seed oil-based biodiesel. *Energy Convers. Manag.* **2014**, *78*, 266–275. [CrossRef]
81. Al-Zuhair, S.; Hussein, A.; Al-Marzouqi, A.H.; Hashim, I. Continuous production of biodiesel from fat extracted from lamb meat in supercritical CO_2 media. *Biochem. Eng. J.* **2012**, *60*, 106–110. [CrossRef]
82. Aransiola, E.F. Production of biodiesel from crude neem oil feedstock and its emissions from internal combustion engines. *Afr. J. Biotechnol.* **2012**, *11*, 6178–6186. [CrossRef]
83. Costa, J.F.; Almeida, M.F.; Alvim-Ferraz, M.C.M.; Dias, J.M. Biodiesel production using oil from fish canning industry wastes. *Energy Convers. Manag.* **2013**, *74*, 17–23. [CrossRef]
84. Katre, G.; Joshi, C.; Khot, M.; Zinjarde, S.; RaviKumar, A. Evaluation of single cell oil (SCO) from a tropical marine yeast *Yarrowia lipolytica* NCIM 3589 as a potential feedstock for biodiesel. *AMB Express* **2012**, *2*, 1–14. [CrossRef] [PubMed]
85. Kaur, S.; Sarkar, M.; Srivastava, R.B.; Gogoi, H.K.; Kalita, M.C. Fatty acid profiling and molecular characterization of some freshwater microalgae from India with potential for biodiesel production. *New Biotechnol.* **2012**, *29*, 332–344. [CrossRef] [PubMed]
86. Khot, M.; Kamat, S.; Zinjarde, S.; Pant, A.; Chopade, B.; RaviKumar, A. Single cell oil of oleaginous fungi from the tropical mangrove wetlands as a potential feedstock for biodiesel. *Microb. Cell Fact.* **2012**, *11*, 1–13. [CrossRef] [PubMed]
87. Liu, B.; Zhao, Z.K. Biodiesel production by direct methanolysis of oleaginous microbial biomass. *J. Chem. Technol. Biotechnol.* **2007**, *82*, 775–780. [CrossRef]
88. Rashid, U.; Ibrahim, M.; Yasin, S.; Yunus, R.; Taufiq-Yap, Y.H.; Knothe, G. Biodiesel from *Citrus reticulata* (mandarin orange) seed oil, a potential non-food feedstock. *Ind. Crops Prod.* **2013**, *45*, 355–359. [CrossRef]
89. Sani, W. Multistage Methanolysis of Crude Palm Oil for Biodiesel Production in a Pilot Plant. Ph.D. Thesis, Universiti Tun Hussein Onn Malaysia, Parit Raja, Malaysia, 2014.
90. Silitonga, A.S.; Ong, H.C.; Mahlia, T.M.I.; Masjuki, H.H.; Chong, W.T. Characterization and production of *Ceiba pentandra* biodiesel and its blends. *Fuel* **2013**, *108*, 855–858. [CrossRef]
91. Zhou, X.; Ge, H.; Xia, L.; Zhang, D.; Hu, C. Evaluation of oil-producing algae as potential biodiesel feedstock. *Bioresour. Technol.* **2013**, *134*, 24–29. [CrossRef] [PubMed]
92. Knothe, G. “Designer” biodiesel: Optimizing fatty ester composition to improve fuel properties. *Energy Fuels* **2008**, *22*, 1358–1364. [CrossRef]
93. Vauhkonen, V.; Niemi, S.; Hiltunen, E.; Salminen, H.J.; Pasila, A. The first-generation biodiesel: The effects of raw material on physical properties, oxidation stability and emissions. In Proceedings of the International Conference on Clean Electrical Power, Capri, Italy, 19–11 June 2009; pp. 17–123.
94. Ashraful, A.M.; Masjuki, H.H.; Kalam, M.A.; Rizwanul Fattah, I.M.; Imtenan, S.; Shahir, S.A.; Mobarak, H.M. Production and comparison of fuel properties, engine performance, and emission characteristics of biodiesel from various non-edible vegetable oils: A review. *Energy Convers. Manag.* **2014**, *80*, 202–228. [CrossRef]
95. Popp, J.; Harangi-Rakos, M.; Gabnai, Z.; Balogh, P.; Antal, G.; Bai, A. Biofuels and their co-products as livestock feed: Global economic and environmental implications. *Molecules* **2016**, *21*, 285. [CrossRef] [PubMed]
96. Yusuf, N.N.A.N.; Kamarudin, S.K.; Yaakub, Z. Overview on the current trends in biodiesel production. *Energy Convers. Manag.* **2011**, *52*, 2741–2751. [CrossRef]
97. Shahbazi, M.R.; Khoshandam, B.; Nasiri, M.; Ghazvini, M. Biodiesel production via alkali-catalyzed transesterification of Malaysian RBD palm oil—Characterization, kinetics model. *J. Taiwan Inst. Chem. Eng.* **2012**, *43*, 504–510. [CrossRef]

98. Kuss, V.V.; Kuss, A.V.; da Rosa, R.G.; Aranda, D.A.G.; Cruz, Y.R. Potential of biodiesel production from palm oil at Brazilian Amazon. *Renew. Sustain. Energy Rev.* **2015**, *50*, 1013–1020. [CrossRef]
99. Sumathi, S.; Chai, S.P. Mohamed, A.R. Utilization of oil palm as a source of renewable energy in Malaysia. *Renew. Sustain. Energy Rev.* **2008**, *12*, 2404–2421. [CrossRef]
100. Magat, S.S. Understanding Right, the Productivity (Yield) of Coconut from the Philippines' Research and Field Experience: A Knowledge Tool for Industry Development and Management (A Research Notes). 2001. Available online: http://www.pca.da.gov.ph/coconutrde/images/yield.pdf (accessed on 23 October 2017).
101. Muppaneni, T.; Reddy, H.K.; Ponnusamy, S.; Patil, P.D.; Sun, Y.; Dailey, P.; Deng, S. Optimization of biodiesel production from palm oil under supercritical ethanol conditions using hexane as co-solvent: A response surface methodology approach. *Fuel* **2013**, *107*, 633–640. [CrossRef]
102. Ali, E.N.; Tay, C.I. Characterization of biodiesel produced from palm oil via base catalyzed transesterification. *Procedia Eng.* **2013**, *53*, 7–12. [CrossRef]
103. Ong, H.C.; Mahlia, T.M.I.; Masjuki, H.H.; Norhasyima, R.S. Comparison of palm oil, *Jatropha curcas* and *Calophyllum inophyllum* for biodiesel: A review. *Renew. Sustain. Energy Rev.* **2011**, *15*, 3501–3515. [CrossRef]
104. Mukherjee, I.; Sovacool, B.K. Palm oil-based biofuels and sustainability in Southeast Asia: A review of Indonesia, Malaysia, and Thailand. *Renew. Sustain. Energy Rev.* **2014**, *37*, 1–12. [CrossRef]
105. Gilbert, D. Oil palm and palm oil industry in Ghana: A brief history. *Int. Res. J. Plant Sci.* **2013**, *4*, 158–167.
106. IndexMundi. 2018. Available online: https://www.indexmundi.com/commodities (accessed on 18 July 2018).
107. Tek, J.C.Y.; Chandran, M.R. A century of oil palms in Malaysia. *Inform* **2005**, *16*, 142–143.
108. Demirbas, A. Biodiesel fuels from vegetable oils via catalytic and non-catalytic supercritical alcohol transesterifications and other methods: A survey. *Energy Convers. Manag.* **2003**, *44*, 2093–2109. [CrossRef]
109. Choo, M.C.; Ma, A.N.; Cheah, K.Y.; Majid, R.A.; Yap, A.K.C.; Lau, H.L.N.; Cheng, S.F.; Yung, C.L.; Puah, C.W.; Ng, M.H.; et al. Palm diesel: Green and renewable fuel from palm oil. *Palm Oil Dev.* **2005**, *42*, 3–7.
110. Vijay, V.; Pimm, S.L.; Jenkins, C.N.; Smith, S.J. The impacts of oil palm on recent deforestation and biodiversity loss. *PLoS ONE* **2016**, *11*, 1–19. [CrossRef] [PubMed]
111. Jayed, M.H.; Masjuki, H.H.; Saidur, R.; Kalam, M.A.; Jahirul, M.I. Environmental aspects and challenges of oilseed produced biodiesel in Southeast Asia. *Renew. Sustain. Energy Rev.* **2009**, *13*, 2452–2462. [CrossRef]
112. Hassan, M.N.A.; Jaramillo, P.; Griffin, W.M. Life cycle GHG emissions from Malaysian oil palm bioenergy development: The impact on transportation sector's energy security. *Energy Policy* **2011**, *39*, 2615–2625. [CrossRef]
113. Likozar, B.; Levec, J. Transesterification of canola, palm, peanut, soybean and sunflower oil with methanol, ethanol, isopropanol, butanol and tert-butanol to biodiesel: Modelling of chemical equilibrium, reaction kinetics and mass transfer based on fatty acid composition. *Appl. Energy* **2014**, *123*, 108–120. [CrossRef]
114. Rathmann, R.; Szklo, A.; Schaeffer, R. Targets and results of the Brazilian biodiesel incentive program—Has it reached the promised land? *Appl. Energy* **2012**, *97*, 91–100. [CrossRef]
115. Talukder, M.R.; Wu, J.C.; Fen, N.M.; Li, Y.; Melissa, S. Two-step lipase catalysis for production of biodiesel. *Biochem. Eng. J.* **2010**, *49*, 207–212. [CrossRef]
116. Silitonga, A.S.; Masjuki, H.H.; Mahlia, T.M.I.; Ong, H.C.; Atabani, A.E.; Chong, W.T. A global comparative review of biodiesel production from *Jatropha curcas* using different homogeneous acid and alkaline catalysts: Study of physical and chemical properties. *Renew. Sustain. Energy Rev.* **2013**, *24*, 514–533. [CrossRef]
117. Talebian-Kiakalaieh, A.; Amin, N.A.S.; Mazaheri, H. A review on novel processes of biodiesel production from waste cooking oil. *Appl. Energy* **2013**, *104*, 683–710. [CrossRef]
118. Wan Ghazali, W.N.M.; Mamat, R.; Masjuki, H.H.; Najafi, G. Effects of biodiesel from different feedstocks on engine performance and emissions: A review. *Renew. Sustain. Energy Rev.* **2015**, *51*, 585–602. [CrossRef]
119. Nursal, R.S.; Zali, Z.; Haizri, H.; Amat, C.; Amear, S.; Ariffin, S.; Khalid, A. Comparative study of the performance and exhaust gas emissions of biodiesels derived from three different feedstocks with diesel on marine auxiliary diesel engine. *ARPN J. Eng. Appl. Sci.* **2017**, *12*, 2017–2028.
120. Vieira da Silva, M.A.; Gil Ferreira, B.L.; da Costa Marques, L.G.; Soares Murta, A.L.; de Freitas, M.A.V. Comparative study of NOx emissions of biodiesel-diesel blends from soybean, palm and waste frying oils using methyl and ethyl transesterification routes. *Fuel* **2017**, *194*, 144–156. [CrossRef]

121. Abu-Hamdeh, N.H.; Alnefaie, K.A. A comparative study of almond and palm oils as two bio-diesel fuels for diesel engine in terms of emissions and performance. *Fuel* **2015**, *150*, 318–324. [CrossRef]
122. Ng, J.H.; Ng, H.K.; Gan, S. Characterisation of engine-out responses from a light-duty diesel engine fuelled with palm methyl ester (PME). *Appl. Energy* **2012**, *90*, 58–67. [CrossRef]
123. Sharon, H.; Karuppasamy, K.; Soban Kumar, D.R.; Sundaresan, A. A test on DI diesel engine fueled with methyl esters of used palm oil. *Renew. Energy* **2012**, *47*, 160–166. [CrossRef]
124. Lin, B.F.; Huang, J.H.; Huang, D.Y. Experimental study of the effects of vegetable oil methyl ester on DI diesel engine performance characteristics and pollutant emissions. *Fuel* **2009**, *88*, 1779–1785. [CrossRef]
125. Puhan, S.; Vedaraman, N.; Rambrahamam, B.V.; Nagarajan, G. Mahua (*Madhuca indica*) seed oil: A source of renewable energy in India. *J. Sci. Ind. Res.* **2005**, *64*, 890–896.
126. Choo, Y.M.; Cheng, S.F.; Yung, C.L.; Lau, H.L.N.; Ma, A.N.; Basiron, Y. Palm Diesel with Low Pour Point for Climate Countries. Malaysian Patent No. MY-141001-A, 12 February 2010.
127. Ashnani, M.H.M.; Johari, A.; Hashim, H.; Hasani, E. A source of renewable energy in Malaysia, why biodiesel? *Renew. Sustain. Energy Rev.* **2014**, *35*, 244–257. [CrossRef]
128. Kurnia, J.C.; Jangam, S.V.; Akhtar, S.; Sasmito, A.P.; Mujumdar, A.S. Advances in biofuel production from oil palm and palm oil processing wastes: A review. *Biofuel Res. J.* **2016**, *3*, 332–346. [CrossRef]
129. Johansson, T.B.; Kelly, H.; Reddy, A.K.N.; Williams, R.H. (Eds.) *Renewable Energy: Sources for Fuels and Electricity*; Island Press: Washington, DC, USA, 1993.
130. Kerschbaum, S.; Rinke, G.; Schubert, K. Winterization of biodiesel by micro process engineering. *Fuel* **2008**, *87*, 2590–2597. [CrossRef]
131. Srinivasan, S. The food v. fuel debate: A nuanced view of incentive structures. *Renew. Energy* **2009**, *34*, 950–954. [CrossRef]
132. Tan, K.T.; Lee, K.T.; Mohamed, A.R.; Bhatia, S. Palm oil: Addressing issues and towards sustainable development. *Renew. Sustain. Energy Rev.* **2009**, *13*, 420–427. [CrossRef]
133. Rivera-Mendez, Y.D.; Rodriguez, D.T.; Romero, H.M. Carbon footprint of the production of oil palm (*Elaeis guineensis*) fresh fruit bunches in Colombia. *J. Clean. Prod.* **2017**, *149*, 743–750. [CrossRef]
134. Roundtable on Sustainable Palm Oil. 2017. Available online: https://www.rspo.org (accessed on 23 October 2017).
135. Sheil, D.; Casson, A.; Meijaard, E.; Noordwijk, M.V.; Gaskell, J.; Sunderland-Groves, J.; Wertz, K.; Kanninen, M. *The Impacts and Opportunities of Oil Palm in Southeast Asia: What Do We Know and What Do We Need to Know?* CIFOR Occasional Paper No. 51; Center for International Forestry Research (CIFOR): Bogor, Indonesia, 2009 doi:10.17528/cifor/002792; ISBN 978-979-1412-74-2.
136. Koizumi, T. Biofuels and food security. *Renew. Sustain. Energy Rev.* **2015**, *52*, 829–841. [CrossRef]
137. Chew, T.L.; Bhatia, S. Catalytic processes towards the production of biofuels in a palm oil and oil palm biomass-based biorefinery. *Bioresour. Technol.* **2008**, *99*, 7911–7922. [CrossRef] [PubMed]
138. Sulaiman, S.A.; Taha, F.F.F. Drying of oil palm fronds using concentrated solar thermal power. *Appl. Mech. Mater.* **2015**, *699*, 449–454. [CrossRef]
139. Basiron, Y.; Weng, C.K. The oil palm and its sustainability. *J. Oil Palm Res.* **2004**, *16*, 1–10.
140. Herjanto, E.; Widana, I.D.K.K. Policy analysis: Solar substitution with biodiesel. *J. Pertahanan.* **2016**, *2*, 109–128.
141. Aladetuyi, A.; Olatunji, G.; Ogunniyi, D.S.; Odetoye, T.E.; Oguntoye, S.O. Production and characterization of biodiesel using palm kernel oil; fresh and recovered from spent bleaching earth. *Biofuel Res. J.* **2014**, *4*, 134–138. [CrossRef]
142. Nursulihatimarsyila, A.W.; Cheah, K.Y.; Chuah, T.G.; Siew, W.L.; Choong, T.S.Y. Deoiling and regeneration efficiencies of spent bleaching clay. *Am. J. Appl. Sci.* **2010**, *7*, 434–437. [CrossRef]
143. Ahmad, A.L.; Sumathi, S.; Hameed, B.H. Coagulation of residue oil and suspended solid in palm oil mill effluent by chitosan, alum and PAC. *Chem. Eng. J.* **2006**, *118*, 99–105. [CrossRef]
144. Ngarmkam, W.; Sirisathitkul, C.; Phalakornkule, C. Magnetic composite prepared from palm shell-based carbon and application for recovery of residual oil from POME. *J. Environ. Manag.* **2011**, *92*, 472–479. [CrossRef] [PubMed]
145. Wahi, R.; Chuah, L.; Nourouzi, M.; Ngaini, Z.; Choong, T.; Yaw, S. Utilization of esterified sago bark fibre waste for removal of oil from palm oil mill effluent. *J. Environ. Chem. Eng.* **2017**, *5*, 170–177. [CrossRef]

146. Lam, M.K.; Lee, K.T. Renewable and sustainable bioenergies production from palm oil mill effluent (POME): Win-win strategies toward better environmental protection. *Biotechnol. Adv.* **2011**, *29*, 124–141. [CrossRef] [PubMed]
147. Akinfalabi, S.I.; Rashid, U.; Yunus, R.; Taufiq-Yap, Y.H. Synthesis of biodiesel from palm fatty acid distillate using sulfonated palm seed cake catalyst. *Renew. Energy* **2017**, *111*, 611–619. [CrossRef]
148. Al-Widyan, M.I.; Al-Shyoukh, A.O. Experimental evaluation of the transesterification of waste palm oil into biodiesel. *Bioresour. Technol.* **2002**, *85*, 253–256. [CrossRef]
149. Cho, H.J.; Kim, J.K.; Hong, S.W.; Yeo, Y.K. Development of a novel process for biodiesel production from palm fatty acid distillate (PFAD). *Fuel Process. Technol.* **2012**, *104*, 271–280. [CrossRef]
150. Chongkhong, S.; Tongurai, C.; Chetpattananondh, P.; Bunyakan, C. Biodiesel production by esterification of palm fatty acid distillate. *Biomass Bioenergy* **2007**, *31*, 563–568. [CrossRef]
151. Surasit, C.; Yoosuk, B.; Pohmakotr, M. Biodiesel synthesis from palm fatty acid distillate using tungstophosphoric acid supported on cesium—Containing niobia. *J. Am. Oil Chem. Soc.* **2017**, *94*, 465–474. [CrossRef]
152. Astar, I.; Usman, T.; Wahyuni, N.; Rudiyansyah; Alimuddin, A.H. Bifunctional heterogeneous catalysts from oil palm empty fruit bunches ash and alum for biodiesel synthesis simultaneously. *AIP Conf. Proc.* **2017**, *1823*, 1–6. [CrossRef]
153. Manurung, R.; Ramadhani, D.A.; Maisarah, S. One step transesterification process of sludge palm oil (SPO) by using deep eutectic solvent (DES) in biodiesel production. *AIP Conf. Proc.* **2017**, *1855*, 1–9. [CrossRef]
154. Skrbic, B.; Predojevic, Z.; Durisic-Mladenovic, N. Esterification of sludge palm oil as a pretreatment step for biodiesel production. *Waste Manag. Res.* **2015**, *33*, 723–729. [CrossRef] [PubMed]
155. Ricca, R.N.; Md, Z.A.; Mohammed, S.J. Enzymatic biodiesel production from sludge palm oil (SPO) using locally produced *Candida cylindracea* lipase. *Afr. J. Biotechnol.* **2013**, *12*, 4966–4974. [CrossRef]
156. Hidayat, A.; Sutrisno, B. Esterification free fatty acid in sludge palm oil using ZrO_2/SO_4^{2-}-rice husk ash catalyst. *AIP Conf. Proc.* **2017**, *1840*, 1–6. [CrossRef]
157. Ngaini, Z.; Shahrom, F.D.; Jamil, N.; Wahi, R.; Ahmad, Z.A. *Imperata cylindrica* sp as novel silica-based heterogeneous catalysts for transesterification of palm oil mill sludge. *J. Oleo Sci.* **2016**, *65*, 507–515. [CrossRef] [PubMed]
158. Aranda, D.A.G.; Santos, R.T.P.; Tapanes, N.C.O.; Ramos, A.L.D.; Antunes, O.A.C. Acid-catalyzed homogeneous esterification reaction for biodiesel production from palm fatty acids. *Catal. Lett.* **2008**, *122*, 20–25. [CrossRef]
159. Babu, A.R.; Amba Prasad Rao, G.; Hari Prasad, T. Experimental investigations on a variable compression ratio (VCR) CIDI engine with a blend of methyl esters palm stearin-diesel for performance and emissions. *Int. J. Ambient Energy* **2017**, *38*, 420–427. [CrossRef]
160. Baroutian, S.; Aroua, M.K.; Raman, A.A.; Sulaiman, N.M. RBD palm olein-based methyl/ethyl esters. *J. Oil Palm Res.* **2009**, *21*, 659–666.
161. Choi, C.S.; Kim, J.W.; Jeong, C.J.; Kim, H.; Yoo, K.P. Transesterification kinetics of palm olein oil using supercritical methanol. *J. Supercrit. Fluids* **2011**, *58*, 365–370. [CrossRef]
162. Sakdasri, W.; Sawangkeaw, R.; Ngamprasertsith, S. Continuous production of biofuel from refined and used palm olein oil with supercritical methanol at a low molar ratio. *Energy Convers. Manag.* **2015**, *103*, 934–942. [CrossRef]
163. Suwanno, S.; Rakkan, T.; Yunu, T.; Paichid, N.; Kimtun, P. The production of biodiesel using residual oil from palm oil mill effluent and crude lipase from oil palm fruit as an alternative substrate and catalyst. *Fuel* **2017**, *195*, 82–87. [CrossRef]
164. Klabsong, M.; Kungskulniti, N.; Puemchalad, C. Feasibility study of biodiesel production from residual oil of palm oil mill effluent. *Int. J. GEOMATE* **2017**, *12*, 60–64. [CrossRef]
165. Hindryawati, N.; Erwin; Maniam, G.P. Esterification of oil adsorbed on palm decanter cake into methyl ester using sulfonated rice husk ash as heterogeneous acid catalyst. *AIP Conf. Proc.* **2017**, *1813*, 1–11. [CrossRef]
166. Suryani, A.; Mubarok, Z.; Suprihatin; Romli, M.; Yunira, E.N. Process design of in situ esterification—Transesterification for biodiesel production from residual oil of spent bleaching earth (SBE). *IOP Conf. Ser. Earth Environ. Sci.* **2017**, *65*, 1–11. [CrossRef]
167. Maulidiyah; Nurdin, M.; Fatma, F.; Natsir, M.; Wibowo, D. Characterization of methyl ester compound of biodiesel from industrial liquid waste of crude palm oil processing. *Anal. Chem. Res.* **2017**, *12*, 1–9. [CrossRef]

168. Cho, H.J.; Kim, J.K.; Cho, H.J.; Yeo, Y.K. Techno-economic study of a biodiesel production from palm fatty acid distillate. *Ind. Eng. Chem. Res.* **2013**, *52*, 462–468. [CrossRef]
169. Botero, C.D.; Restrepo, D.L.; Cardona, C.A. A comprehensive review on the implementation of the biorefinery concept in biodiesel production plants. *Biofuel Res. J.* **2017**, *4*, 691–703. [CrossRef]
170. Ghatak, H.R. Biorefineries from the perspective of sustainability: Feedstocks, products, and processes. *Renew. Sustain. Energy Rev.* **2011**, *15*, 4042–4052. [CrossRef]
171. Gumba, R.E.; Saallah, S.; Misson, M.; Ongkudon, C.M.; Anton, A. Green biodiesel production: A review on feedstock, catalyst, monolithic reactor, and supercritical fluid technology. *Biofuel Res. J.* **2016**, *3*, 431–447. [CrossRef]
172. Schnepf, R.; Yacobucci, B.D. *Renewable Fuel Standard (RFS): Overview and Issues*; CRS Report No. R40155 for U.S. Congress; Congressional Research Service (CRS): Washington, DC, USA, 2010.
173. Akia, M.; Yazdani, F.; Motaee, E.; Han, D.; Arandiyan, H. A review on conversion of biomass to biofuel by nanocatalysts. *Biofuel Res. J.* **2014**, *1*, 16–25. [CrossRef]
174. Bergsma, G.; Kampman, B.; Croezen, H.; Sevenster, M. *Biofuels and Their Global Influence on Land Availability for Agriculture and Nature. A First Evaluation and a Proposal for Further Fact Finding*; Report, CE Delf: Delf, The Netherlands, 2007.
175. Goenadi, D.H. Perspective on Indonesian palm oil production. In Proceedings of the International Food & Agricultural Trade Policy Council's Spring 2008 Meeting, Bogor, Indonesia, 12 May 2008; pp. 1–4.
176. Reijnders, L.; Huijbregts, M.A.J. Palm oil and the emission of carbon-based greenhouse gases. *J. Clean. Prod.* **2008**, *16*, 477–482. [CrossRef]